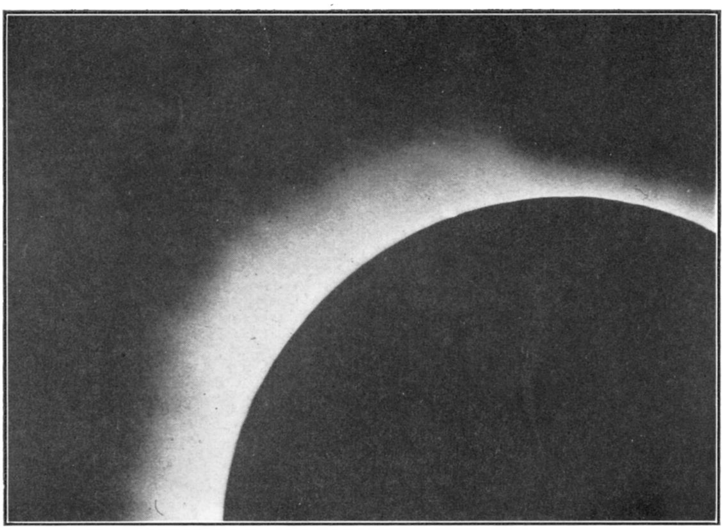
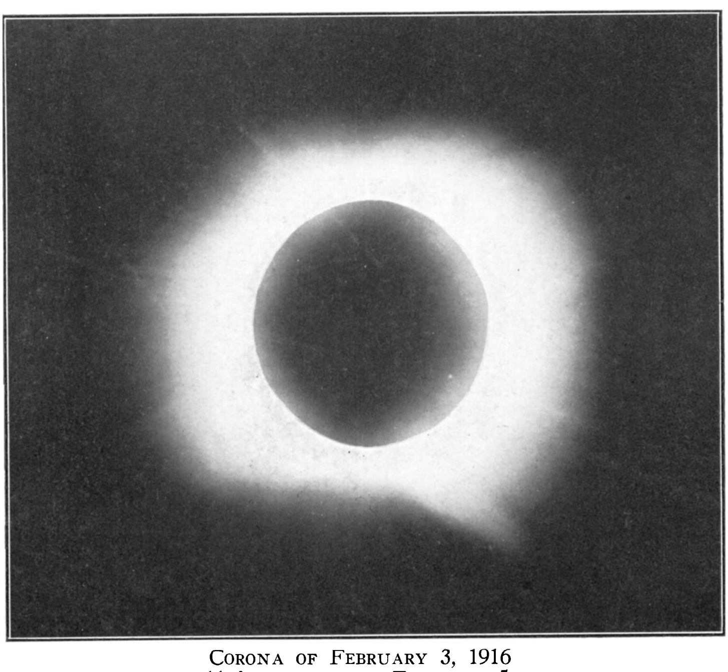


Hoods over Prominence in Southwest Quadrant
Exposure 2^s. Enlarged 2.8 diameters



Corona of February 3, 1916
11-foot camera. Exposure 5^s

THE SOLAR SYSTEM*

BY W. W. CAMPBELL.

The study of astronomy begins naturally with the solar system. The solar system is our abode. It is the observing station from which we look out in all directions to the great stellar system. The solar system is only a minute detail in the structure of the universe. He who would explore the universe should begin by knowing his immediate surroundings. Our visual telescopes could show us sixty or seventy millions of stars, distributed over the whole sky, and our great reflecting telescopes could photograph possibly two or three times as many. With only one exception all of these stars are so far away that they are seen as mere points of light in our most powerful telescope, even when the magnification is nearly 3,000 diameters. The one exceptional star is our Sun: It alone of all the stars can be seen to have a "diameter." It alone of all the stars can be studied in any geometric detail by means now available. This is because our Sun is relatively near to us. The next nearest star known, *Alpha Centauri,* is 275 thousand times as far away from us as our star is. If we would know what the stars in general are we should begin by learning about our own star. That is the chief reason why there are solar observatories in many countries of the world. Those institutions are occupied wholly or chiefly in the study of the Sun. Our Sun is an exceedingly interesting body in itself, especially for beings who live in the solar system, but its main interest to astronomers lies in the fact that knowledge of conditions existing in our Sun enables us to draw many conclusions concerning conditions existing in millions of other suns.

It is not our purpose to describe the solar system in detail; nor shall we burden the lecture by quoting the enormous distances which separate the heavenly bodies: astronomers do not comprehend them any better than the laymen do. One or two distances, one or two masses, will be sufficient to serve as scale values for the entire system. We shall make it our chief concern to emphasize the characteristic features of the

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solar system so that we may comprehend the relation of its different members to each other, and the relation of the solar system as a whole to the great stellar system. We shall try to visualize the solar system as it exists in space, highly isolated from all other members of the stellar system.

The solar system consists of the great central Sun, the eight[1] major planets and their twenty-six satellites, the more than 800 minor planets or asteroids, the zodiacal light materials, the comets and the meteors. Only one other class of bodies is known to astronomers: the nebulæ. Now many of the nebulæ are far out in the stellar system, and a great many others may be outside of our stellar system. Certainly none of the nebulæ existing today have a direct connection with our solar system.

We have said that the Sun is one of the ordinary stars. Compared with the thousands of other stars visible to the unassisted eye on any clear night, our Sun is merely an average star. Nevertheless it is a very large body. Its diameter is 110 times the Earth's diameter. Its volume is therefore 1,300,000 times the Earth's volume. If the Sun were a hollow shell of its present diameter, we could pour more than a million Earths into it and still leave empty the space between the Earth-balls.

The average density of the Earth is five and a half times that of water. The average density of the Sun is only a quarter that of the Earth; that is, the Sun is forty per cent. more dense than water. From the figures quoted it follows that the mass of the Sun, in other words, the quantity of material that the Sun contains, is 333,000 times that of the Earth. It is this immense mass which gives the Sun its tremendous gravitational power, a power sufficient to maintain the planets in their elliptic orbits around it.

At an average distance of ninety-three millions of miles from the Sun are the Earth and its Moon. The Earth-Moon system revolves once around the Sun in what we have agreed to call our year. To complete the circuit in the year requires the Earth to travel a little more than eighteen miles and a

[1] These are the numbers known to exist in the year 1916

half per second. Between the Earth and the Sun are two known planets, *Mercury* and *Venus*. *Mercury* is a little planet, 3,000 miles in diameter, whose average distance from the Sun is about three-eighths the Earth's distance. It is so close to the Sun that it must travel very rapidly in its orbit, an average of twenty-eight miles per second, to keep from being drawn into the Sun. Relatively few people have seen *Mercury*. It does not get very far away from the Sun, but if observers know when it is going to be at its greatest distance east of the Sun shortly after sunset and west of the Sun shortly before sunrise, they would have no difficulty in seeing the planet as a first magnitude star low in the sky, and small telescopes would show the planet's disc.

The planet *Venus,* whose orbit lies between those of *Mercury* and the Earth, is for those who live on the Earth the most brilliant of all the planets. It is just a shade smaller than the Earth in size. The Earth, as you know, is a little over 7,900 miles in diameter. The diameter of *Venus* is 7,700 miles. Its distance from the Sun is not quite two-thirds the Earth's distance. It requires seven and a half of our months to complete its journey around the Sun.

Going outward from the Earth we come to our interesting neighbor *Mars*. It is fifty per cent. farther from the Sun than we are, and its year is a little under two of our years. Its diameter is slightly more than one-half the Earth's diameter—about 4,200 miles. It is therefore a little larger than *Mercury* and a good deal smaller than *Venus* and the Earth. It has two tiny moons. The smaller one is only eight or ten miles in diameter, and the larger one less than forty miles. The surface areas of these little satellites are smaller than some of the counties in California.

Next in order of distance from the Sun are the asteroids, or little planets. The first one was discovered on the first day of the last century, and up to the present time more than 800 have been found. It is not an uncommon thing for ten or fifteen of these bodies to be discovered in a single year, by means of photography. The first one discovered is, so far as we know, the largest: a little less than 500 miles in diameter. The smallest ones are certainly less than ten miles in diameter.

The largest of our planets is *Jupiter*, whose average distance from the Sun is a little over five times the Earth's distance. *Jupiter's* diameter is eleven times the Earth's. Its volume is therefore thirteen hundred times the Earth's volume, and if that planet were a hollow shell you could pour more than one thousand Earth's into it. *Jupiter* requires nearly twelve years to complete its circuit, at an average speed of eight miles per second. This great planet is known to have nine satellites. The four bright moons, visible even with opera glasses, were the first celestial bodies discovered by Galileo and his telescope—in the year 1610. It is of special interest to Californians to note in passing that the fifth moon of *Jupiter* was discovered with the 36-inch refractor of the Lick Observatory in 1892; the sixth and seventh moons with the Crossley reflector of the Lick Observatory in 1904-5; and the ninth satellite with the Crossley reflector in 1914. The eighth was discovered at the Royal Observatory, Greenwich, in 1908.

Still farther from the Sun is *Saturn* with its wonderful ring system and nine known moons. Its diameter is nine times that of the Earth, and it goes once around the Sun in a little less than thirty years. Maxwell and Keeler proved that the rings are a great collection of little moons—probably millions of them.

The six major planets already named were well known to the ancients. References to them are frequent in the extant literature of the nations, past and present. The planet next in distance, *Uranus,* was discovered by Sir William Herschel in 1781 in one of his famous sweepings of the heavens. It is nineteen times as far from the Sun as the Earth, its diameter is four times the Earth's, and, traveling four miles per second, it requires eighty-four years to complete the circuit of the Sun. It has four known satellites.

The discovery of the next planet, *Neptune,* was, as you know, a great event in the history of astronomy. *Uranus* did not follow precisely the path marked out for it by astronomers, and Adams of Cambridge in 1845, and Leverrier of Paris independently a year later, proved that the discrepancies in its motion could be caused by the attractions

of an undiscovered planet farther from the Sun than itself. They computed the position of the undiscovered planet. Adams tried to enlist the services of the greatest telescopes in England to discover the body, but his advice and requests were neglected. It is especially appropriate in these days of war between the nations to note this illustration of the international character of astronomical research: Leverrier of Paris requested Astronomer Galle of Berlin to search for the new planet, with the largest telescope on the continent. Galle found the planet on the first night of the search, almost exactly where Leverrier said it would be. *Neptune* is a little over four times the Earth in diameter, and he requires 165 years to travel through his orbit. He has gone less than half way around the Sun since his discovery. *Neptune* has one known moon.

It is not impossible that other planets more distant than *Neptune* are revolving around the Sun. Several astronomers have devoted much time to searching for them.

The Earth-Moon system is a unique combination, in that the two bodies are more nearly of the same size than are any other planet and its satellites. The Moon's diameter is considerably over a fourth of the Earth's diameter. It required the Washington 26-inch telescope to discover the two tiny moons of *Mars*, but an astronomer on *Mars* or on *Venus*, when those planets are in favorable positions, would not need any telescope at all to see the Earth and its Moon as a double planet—the only double planet, so to speak, in the solar system.

It is a most remarkable fact that all of the eight major planets and all of the more than 800 asteroids revolve around the Sun in the same direction, which astronomers have agreed to call from west to east. There is no exception to this rule. It is an equally remarkable fact that the eight planets revolve in orbits lying nearly in the same plane, and that the average position of the orbital planes of the 800 asteroids coincides closely with the average for the eight planets. Let us refer the planes of the orbits of the planets and asteroids to what we may call the average plane of the planets' orbits. *Mercury's* orbit is inclined six degrees to

the average plane, and *Venus's* orbit two degrees. The orbit planes of the other five planets are inclined, without exception, less than two degrees to the average plane of the system. The orbit planes of a few of the little asteroids are inclined as much as thirty or forty degrees to the plane of the system, but the great majority of the asteroids do not get far from that plane.

Other striking and related facts are these: The Sun rotates on his axis from west to east. We do not positively know the directions of rotation for *Mercury* and *Venus,* but there are reasons for thinking that their direction is also from west to east. Our Moon revolves around the Earth from west to east, and the Earth and Moon both rotate on their axes from west to east. *Mars* rotates from west to east, and his two moons revolve around the planet from west to East. *Jupiter* and *Saturn* rotate on their axes from west to east, but in the satellite systems of these planets and in the systems of *Uranus* and *Neptune* we come upon exceptions to the west-to-east rule. The seven inner satellites of *Jupiter* revolve from west to east, but the eighth and ninth satellites, which are farther out from the planet than the other seven, travel from east to west. The eight inner satellites of *Saturn* travel from west to east, but the far-out ninth reverses the direction. The four moons of *Uranus* revolve around that planet in a plane which is nearly at right angles to the average plane of the planets, and the plane of the satellites of *Uranus* is probably the approximate plane of the equator of that planet. The satellite of *Neptune* revolves around its planet from east to west in a plane inclined at an angle of thirty-five degrees with the plane of the planets. We should note that the exceptional cases refer to the outermost planets of the solar system, *Uranus* and *Neptune,* and to the outermost satellites in the systems of *Jupiter* and *Saturn.* Everywhere else in the solar system prevails the rule of motions of revolution and rotation from west to east.

The solar system, of great extent in the plane of the system, is an exceedingly thin system. Let us call the distance from the Sun to the Earth one; then the distance from the Sun to the outermost planet, *Neptune,* on the same scale is

thirty, and the diameter of *Neptune's* orbit is sixty. Now our system of Sun, planets, satellites and asteroids lies so nearly in one plane that we could put it in a very flat band-box, sixty units in diameter and one unit in thickness, so that the major planets and their satellites, and all the asteroids, with a very few exceptions, would perform their motions entirely within the box. The exceptional asteroids and the majority of the comets would dip out of the box on one side or the other because the planes of their orbits make considerable angles with the central plane of the solar system.

I want to call your attention as forcibly as possible to the extreme isolation of our system from other systems. If it is one unit of distance from the Sun to the Earth and thirty units from the Sun to the outermost of our planets, *Neptune,* it is, on the same scale 275,000 units to the nearest star of which we have any knowledge, *Alpha Centauri.* It is about 400,000 units in an entirely different direction to our second nearest neighbor, and so on. Most of the comets and some of the meteors, as we shall learn in the next lecture, travel out much farther from the Sun than *Neptune* is; but, aside from some of the comets and meteors, we do not know that there is anything in space between *Neptune,* thirty units from the Sun, and the nearest star, several hundred thousand units from the Sun.

Let us illustrate our isolation in still another way. Light travels from the Sun to the Earth in eight and one-third minutes, and from the Sun to *Neptune* in four and a half hours; but it requires four and a half years to travel from our Sun to the next nearest star, *Alpha Centauri.* The distance of *Alpha Centauri* is described as four and a half light-years. The average distances between the stars are six or seven or eight light-years.

It must be clear that the stars and the planets occupy little space, and that they have a superabundance of room to move about. We have found that the average speed of the naked-eye stars in their motions thru space is about sixteen miles per second, which means that if one star should start to travel precisely toward its nearest neighbor, assuming its

nearest neighbor to be at the average distance, it would require some eighty thousand years to arrive at its destination. Now the diameter of our Sun, an average star, is not more than one fifty-millionth as great as the average distance between neighboring stars. Under such conditions it is not difficult to see that a collision of two stars must be an exceedingly rare event. The approach of two stars so close as to disturb each other violently must also be rare. However, when we consider the number of stars in the stellar system, we should perhaps expect a few close approaches to occur within a human lifetime.

The researches of the early astronomers were confined almost exclusively to the solar system. Their small and imperfect telescopes lacked the power, and their methods lacked the accuracy for attacking the problem of the distant stars. They made a specialty of the motions of the bodies which compose the solar system, of their forms and dimensions, and of their orbits. Their labors, supplemented by that of astronomers still living, have been so thoro and complete that we can predict the motions of the planets around the Sun and the motions of the satellites around the planets with very great accuracy. It would be possible to compute the point in the sky which the planet *Jupiter* will occupy one hundred years from this evening, and the telescope could this year be directed to that point so accurately that, on looking thru the telescope one hundred years from tonight when the clock said the precise second had arrived, the planet would be seen very close to the center of the telescopic field of view. The eclipses of the Sun are computed so accurately that the astronomer may, if he chooses, go years in advance to the proper point for observing a given eclipse and direct his telescope so precisely to the position which the eclipsed Sun will occupy as to witness the phenomenon when it arrives, without more than a minute change in the pointing of his instrument. The pointing of the instrument would probably not be exactly right, because the Moon deviates a little from the path laid down for it; astronomers do not know why. It has, in fact, been suggested that the Moon's motion may be affected slightly by some force or forces

whose nature has not yet been determined. There is likewise an appreciable discrepancy in the motion of *Mercury*. Whether this discrepancy will ever be removed by virtue of a more complete application of Newton's law of gravitation to the problem is uncertain; some other force than gravitation may be acting, but it need be only a very minute force.

The zodiacal light, a faint illumination of the sky visible above the Sun when the Sun is a few degrees below the horizon, is an interesting phenomenon surrounding the Sun. There is no reason to doubt that the zodiacal light which we see comes originally from the Sun, and that this light falls upon and is scattered by finely divided material—dust grains or very small bodies in great numbers which revolve around the Sun, each such particle in effect a little planet. This material is distributed thru a great volume of space, somewhat in the shape of a double-convex lens whose center coincides with the Sun and whose edge extends out even farther than the Earth's orbit. Its shorter dimension extends so far to the north and to the south of the Sun that northern observers, well situated, may see the zodiacal light at midnight in May, June and July above the northern horizon.

Belonging to the solar system also are the comets, which pass around the Sun in orbits for the most part very elongated. We shall study the comets in the next lecture.

There are the meteors, many of which revolve around the Sun in orbits which mark them as members of the Sun's system. It is probable that some of the meteors are merely passing thru the Sun's system and are not of it. Occasionally a meteorite gets down thru our atmosphere to the Earth's surface, is found, and is installed in a museum; but many millions which collide with our atmosphere every twenty-four hours are consumed by the friction of the Earth's atmosphere and lose their identities.

The distribution of the material in the solar system is most remarkable. Nearly all of it is in the Sun. If we add together the masses of the major planets, their satellites, the hundreds of asteroids, make liberal allowance for the masses of the comets, meteors and zodiacal-light materials, and call

the total one, then the mass of the Sun on the same scale is 744; that is, of 745 parts of matter composing our solar system 744 parts are in the Sun and only one part is in the bodies revolving around it. To state this in another way: ninety-nine and six-sevenths per cent. of the material of the solar system is in the Sun, and only one-seventh of one per cent. is divided up to make the planets, satellites, asteroids, etc. The four outer planets, *Jupiter, Saturn, Uranus* and *Neptune,* contain 225 times as much material as the four inner planets, *Mercury, Venus, Earth* and *Mars.* The Earth is fully 3,000 times as massive as the more than 800 asteroids combined. It is not known how much material is responsible for the zodiacal light. The more finely divided that material is, the smaller is the total mass required to reflect and scatter the quantity of solar light observed in that phenomenon. Seeliger has thought that the scattered zodiacal light materials, if condensed into one body, might have a mass fairly comparable to that of the little planet *Mercury,* and he has concluded that the attractions of the zodiacal light materials upon the planet *Mercury* could explain the deviations of that planet from its computed orbit. This problem cannot yet be regarded as definitely settled. For several decades astronomers thought there might exist an undiscovered planet or planets of considerable size between the Sun and the orbit of *Mercury* whose attractions upon *Mercury* were responsible for the discrepancies in its motion. The work of the Crocker eclipse expeditions from the University of California is morally conclusive that there are no such planets massive enough to explain the observed discrepancies. We do not know the mass of any single comet, but we do know that cometary masses are exceedingly small in comparison with the masses of the smallest planets. The recent comets which have approached close to *Mars, Earth, Mercury* or *Venus* have produced no appreciable disturbances in the motions of those planets.

We have described the known members of the solar system as to dimensions, masses, orbits and geometrical relations and situations one to another. We have seen that they form the Sun's system—a system very completely isolated in space,

and independent of other systems so far as its internal relations are concerned. Now the solar system as a whole is traveling thru space with reference to the other members of the stellar system. Sir William Herschel suggested, a century and a third ago, that the apparent motions of the other stars were such as to indicate a motion of our star and its system toward the constellation *Hercules,* and this conclusion has been amply verified by Herschel's successors. The logic of the demonstration is very simple. Let us use an illustration which every one has had or may have the opportunity to test. Suppose the observer is traveling rapidly by railway train across a level tract of country, say toward the west. He will notice that the trees, buildings, or other objects on his western horizon appear to separate gradually. Similar observations on the trees and other objects on the eastern horizon will show that they appear to approach each other. The trees and buildings on the horizon to the right and to the left of him will seem to be traveling toward the east. The explanation is apparent. The motion of the solar system thru space is a much more complicated problem, in that we must deal with space of three dimensions, instead of the two dimensions of the terrestrial surface, and the stellar objects which the observer sees in all directions from him are themselves in motion. However, if the positions of a great number of stars have been accurately determined at some past epoch, as was indeed the case, and the recent determinations of positions of the same stars be compared with the early positions, it will be found that the stars have moved. They will have moved with a great variety of speeds in a great variety of directions; but if the stellar motions are studied with care, it will be found that the prevailing motion of any great group of stars in any large area of the sky will be away from the region of the the constellation *Hercules* and toward the opposite point of the sky. Herschel reasoned truly that this prevailing drift of the stars away from the constellation *Hercules* was due to the motion of the solar system, year after year, decade after decade, toward that constellation. Modern solutions of the same problem have changed the estimated position of the Sun's goal very slightly toward the

southeast, to a point near the boundary line between the constellations *Hercules* and *Lyra*. Astronomers did not succeed in determining the speed of the solar motion from these apparent motions of the stars. The difficulty lay in the fact that we did not know the distances of the stars whose angular motions had been observed. The spectrograph has enabled the second part of the problem to reach a satisfactory solution. This wonderful instrument enables us to measure the motions of approach and recession of the stars, and this has been done for 2,000 or more of the stars, chiefly under the auspices of the University of California, by the Lick Observatory for the northern stars, and by the D. O. Mills Expedition to Santiago, Chile, for the southern stars. It has been found that the stars have a great variety of motions of approach and recession. If we examine the results for a hundred neighboring stars in some one large area of the sky, we shall find that a few will be approaching the solar system at high speed, others will be receding from our system at high speed, and the others will be represented by a great variety of motions of approach and recession. This happens for great groups of stars in any part of the sky. If we consider the observed motions of 100 stars in and surrounding the constellations *Hercules* and *Lyra,* we shall find the same variety of speeds, but if we take the average speed of the group we shall find that the group as a whole seems to be approaching us at the rate of about twelve and a quarter miles per second. In a similar manner, if we consider the motions of 100 neighboring stars in precisely the opposite region of the sky, we shall find the same variety of approach and recession, but we shall obtain for the average speed of the 100 stars as a group an apparent recession of about twelve and a quarter miles per second. No one questions the explanation of these observed facts, that the solar system is traveling toward the *Hercules-Lyra* region with a speed of about twelve and a quarter miles per second with reference to the system of naked-eye stars. Now this speed of motion is carrying the solar system thru space at the rate of approximately 400 million miles per year. There are the best of reasons for believing that our solar system is very old. Its age can

scarcely be less than many tens of millions of years, and more probably hundreds and thousands of millions. It is clear that the youth of the solar system was spent in a very different part of the stellar system from where it now is, and that its old age will be lived in a still different region. We do not know whether the motion of the solar system follows a straight line, or a closed curve such as an ellipse, but the system is probably obeying the gravitational attraction of the rest of the material universe. It seems probable that the orbit is a great ellipse, whose circuit is so great that many hundreds of millions of years will be required to travel over it once, even tho our system meet with no disturbing element in the meantime.

It will be profitable to consider briefly the conditions existing in the Sun and planets. Geologists have been able to study in a limited way the outcropping geologic strata of the Earth, but all of these strata combined are only a few miles in thickness. There are indirect ways of studying the interior of the Earth, and essentially every modern student of the subject has come to the conclusion that the interior of the Earth is solid thruout, with the possible exception of relatively small pockets of molten matter here and there. We know something about the oceans and the atmosphere of the Earth. Do any of the other planets resemble the Earth? *Mercury, Venus* and *Mars* certainly have some resemblances to our planet, but the giant planets *Jupiter, Saturn, Uranus* and *Neptune* are extremely unlike the Earth. The Earth appears to be the densest of all the planets, tho considerable uncertainty exists as to the density of *Mercury. Venus* is about nine-tenths as dense as the Earth, and *Mars* is about seven-tenths. The four great planets average about one-fifth the density of the Earth. *Jupiter; Uranus* and *Neptune* are a little more dense than water, whereas *Saturn* is so light that if it could be thrown upon a great terrestrial ocean it would float like a piece of wood.

We can get no trace of an atmosphere on *Mercury,* and much remains to be done in the way of investigating the atmosphere of *Venus.* The later. planet certainly has an atmosphere, but whether it is comparable in quantity and

chemical composition with the Earth's atmosphere we do not know. As *Venus* is only a shade smaller than the Earth, we should expect the atmosphere of the two planets to be not very unequal. We know that *Mars* has an atmosphere, but it is a very light one. The Martian atmosphere at the surface of that planet is probably not over one-half the density of the Earth's atmosphere at the summit of Mount Everest, our highest mountain peak. There is no reason to doubt that the composition of the Martian atmosphere is very much like our own. A great white area around the north pole of *Mars* waxes and wanes with the coming and going of winter in the northern hemisphere of Mars, and a similar white cap comes and goes at the south pole of the planet. These are just such phenomena as occur every year on the Earth. If we were transported a few thousand miles above the northern hemisphere of the Earth, we should see a great white cap growing in the fall and winter from the Arctic regions southward across Europe and Asia to the latitudes of the Mediterranean Sea and the Himalaya Mountains, and across Canada and the United States well toward the Gulf of Mexico; and we should see the southern edge of this cap retreating northward with the advent of spring and summer. An observer over the southern hemisphere of the Earth would witness the annual waxing and waning of the white cap around the south pole of the Earth, save as the southern oceans interrupted its continuous progress.

The four giant planets have enormously extensive atmospheres. We appear to be able to see at all times clouded areas of tremendous extent. These clouds are more prominent in *Jupiter* than in *Saturn, Uranus* and *Neptune,* but that the surfaces of all four have a very high percentage of clouds we can scarcely doubt. The immense masses of material in these planets and their low average densities lead us unavoidably to conclude that they are not solid, as in the case of the Earth, but that they are largely, and perhaps entirely, in a gaseous state, except as the enormous interior pressures, due to the overlying strata, may liquify or even solidify their central volumes. It is thought that the gaseous strata in each of the four planets extend to great depths and that there is

nothing in the nature of a solid or permanent crust over the surface of any of them. Their low densities probably mean that their enormously deep atmospheres are still quite hot. Yet we have no evidence that any one of them is shining by its own light. When one of *Jupiter's* large satellites passes between the Sun and the planet, eclipsing a small area of the planet's surface, that area appears to be absolutely dark.

We should call attention to the flattened forms of *Jupiter* and *Saturn*. The rotation of the Earth once in about twenty-four hours has caused the equatorial regions to be thrown out by centrifugal force, in effect, and the polar regions to be correspondingly drawn in, until the difference between the equatorial and polar diameters is twenty-six miles. The great planet *Jupiter* rotates on its axis in a little less than ten hours, whereas the little Earth takes twenty-four hours. A point on *Jupiter's* surface is traveling by rotation some twenty-seven times as rapidly as a corresponding point on the Earth's surface. The centrifugal force is enormous, and the result is easily observable in the equatorial and polar diameters, for there is a difference of about 5,000 miles. The effect is even larger in the case of *Saturn,* where the difference of the diameters is nearly 7,000 miles. The throwing of the clouds in the atmospheres of these two planets into belts parallel to the equators is undoubtedly connected with the extremely rapid rotations of the planets, probably thru the medium of trade winds blowing nearly parallel to their equators. If our Earth rotated more and more rapidly our trade winds would approach more and more to parallelism with the equator.

The rings of *Saturn* are unique in the solar system. Maxwell of England proved by mathematics, and Keeler of America proved with the spectroscope, that these rings are a great collection of minute and separate bodies. There are so many of these particles or separate masses that they seem to form a continuous and solid system, except as we see the dark lines dividing them into several component rings. If the rings were solid like a wagon wheel, to use a homely illustration, the outer edge would travel by rotation more rapidly than the inner edge. The spectrograph has shown

that the reverse is the case. A moon at the inner edge of the ring system would have to travel very rapidly to save itself from falling upon the planet. A moon at the outer edge of the ring would travel much more slowly. Keeler proved that each point of the ring system is traveling with the speed which a moon at that distance from the center of the planet would have. Each point in the ring system is a separate moon revolving in an essentially circular orbit about the planet, and in harmony with the gravitational power of the planet.

Our Moon, as you know, is apparently without atmosphere and water, tho it should be said that one astronomer thinks he has observed changes in the bottoms of the lunar craters, such as to suggest the presence of a trace of water in the form of frost. These observations should be verified before they are interpreted on the basis of water vapor. The verification has not yet been provided.

Most interesting of all the bodies in the solar system is the Sun itself. It is an intensely hot sphere whose outer strata, certainly, are gaseous. The gaseous composition may indeed extend from surface to center; but it is much more probable that the great central volume is in the liquid or even solid state, owing to the tremendous pressures which exist there. We know that the surface temperature of the Sun is in effect as high as 10,000° Fahrenheit. The interior temperatures must be vastly higher. The chemical elements known to us could exist at such temperatures only in the form of incandescent gases or vapors, except as immense pressure condenses them to the liquid or solid state. We know that our atmosphere and hydrogen and the other gaseous elements of the Earth can be liquefied and solidified by means of such pressures as our laboratory methods are able to produce. The pressures in the depths of the Sun run up into the millions of pounds per square inch; and, while the temperatures there existing undoubtedly try to preserve the gaseous state of the Sun's interior, the stupendous pressure probably conquers the expansive forces and reduces the central mass to the liquid or solid state. It is scarcely possible that a liquid or solid

core extends from the center out to near the surface of the Sun, for the average density of the entire body is only 1.4 times the density of water.

About forty elements familiar to us on the Earth have been shown to exist in the outer strata of the Sun by means of the spectroscope. Rowland has said that if the Earth were heated up until its temperature is equal to that of the Sun, the Earth's spectrum would probably resemble closely the spectrum of the Sun.

When we look at the Sun we see what we call the photosphere. The prevailing opinion of the photosphere is that it consists of clouds produced by the condensation of some of the vapors, formed in the atmosphere of the Sun when the conditions for condensation are right, very much as our own clouds form in our atmosphere when the conditions are right. The clouds of water vapor with which we are familiar form at a low temperature because we are dealing with water which has a freezing temperature of +32° Fahrenheit. Clouds would be expected to form from iron vapor at a very high temperature, for the freezing point of iron is about 1500° above zero Fahrenheit.

The atmosphere of the Sun is in rapid circulation. There are great storms in its atmosphere, vastly more violent than those in the Earth's atmosphere. In terrestrial storms there are great whirling disturbances in our atmosphere. The sun-spots are to us the outward and visible sign of somewhat similar storms, on a tremendous scale. The motions of gases and vapors in sun-spots have been measured by means of the spectroscope, and Hale has shown that sun-spots are the centers of local magnetic fields. The magnetic field is probably developed in each case by the rapid rotation of electrically charged particles within the volume of spot disturbance.

The sun-spots, as well as other details of the Sun's surface, reveal a curious law of solar rotation. The entire Sun is rotating rapidly from west to east, but the equatorial regions are rotating more rapidly than the regions of high latitude. Areas near the equator rotate once around in twenty-four days, but at forty-five degrees of north and south latitude the rotation period is twenty-eight days, and at seventy-five

degrees of north and south latitude the period is thirty-three days. The forging ahead of the equatorial regions has never been satisfactorily explained.

The sun-spots vary in size most curiously, and for reasons unknown. The spottedness passes from minimum to maximum and back again to minimum in an average period of eleven and one-tenth years. During the years of minimum it is not unusual for the spots to be entirely absent for weeks at a time. The full line curve which represents the spottedness of the Sun as observed from the year 1740 up to 1870 shows that twelve maxima and twelve minima occurred in this interval. The maxima and minima do not come with perfect regularity. Sometimes the maximum is a year or two early, or a year or two late, and similarly for the minima. Many investigators have tried to find an explanation of the sun-spot period, but the results have not been satisfactory. The cause has been looked for in the action of the planets. It would seem that if any of the planets is responsible it should be the giant *Jupiter*. There is no apparent connection, for *Jupiter's* period about the Sun is 11.9 years, whereas the sun-spot period is 11.1 years. It has been suggested that the spots are formed when two or more of our planets are in the same straight line with the Sun, but the fact is that there are just as many spots visible when the planets are equably distributed around the Sun, with no two of them in or near a straight line with the Sun. The cause of periodicity seems to lie within the Sun itself. It is perhaps not impossible that certain forces develop and accumulate within the Sun until they reach the breaking-out intensity, once in eleven years, somewhat after the fashion of the forces which are responsible for the geysers on the Earth. I do not mean to convey the impression that the motions within sun-spots and the motions of water expelled from geysers are the same, as they are not. Experienced investigators have tried to find a relationship between sun-spots and terrestrial weather, but they have not succeeded in proving that such is the case. There have been and still are people who say that the sun-spots rule our weather, but they seem not to know what constitutes a scientific proof; at least, no proof has been published. They

remind me of the small boy's first experience with an electric trolley car. The street-cars in his town had been drawn by horses, and he had no doubt as to the motive power. There came a morning when he and his father got on a successor to the horse-car, and he was interested to know what made the car go. His father tried to explain that it was electricity, but the boy was not convinced, and this is not surprising, for nobody even now knows what electricity is. Before he got to the end of his trolley ride he said, "Father, I have discovered what makes this car go. It is that bell up there above the driver's head, for I have noticed that every time that bell rings the car starts." Therefore, according to the same logic, as there are spots on the Sun and there are rain storms on the Earth, the sun-spots cause the rain. Unfortunately it happens, now and then, that we have an exceedingly dry winter month when the Sun is rich in spots, and a wet month had been prophesied; and that we have an exceedingly wet winter month, now and then, when no spots whatever are visible. It rains no more in the three or four years of sun-spot maximum than it does in the three of four years of sun-spot minimum. Likewise, the storms are no more numerous and no more severe when there are two or three planets almost exactly in line with the Sun than when the planets are equably distributed around the Sun.

In one respect we are sure that the sun-spots do have a terrestrial influence. Magnetic disturbances on the Earth are directly related, in some way, to the sun-spot activity. The curve of magnetic disturbances when correlated with the curve of solar spottedness, shows an agreement that is unmistakable.

Outside and beyond the spherical body of the Sun which we see every clear day are the prominences and the corona. The prominences are certainly connected with, or are the fruits of, the circulatory system of the Sun's atmosphere. They require special spectroscopic apparatus for their observation in ordinary times, but they can be seen directly at times of solar eclipses, when the main body of the Sun is hidden behind the Moon and the background of sky is relatively dark. They are of great variety as to forms and speeds

of development. They sometimes shoot up to heights of two or three hundred thousand miles above the Sun's surface, with speeds as high as 250 miles per second.

The solar corona may also be a product of the rapid circulation within the Sun's structure. It is not impossible that the materials composing the corona are expelled from the Sun by something in the nature of volcanic force, or by the pressure of the intense solar rays upon the minute particles of the corona, or by other force or forces, and that these particles find their way back in descending streams to the Sun. The corona is a part of the Sun. A complete understanding of our Sun requires a study of the corona, and it is chiefly for investigations of this solar appendage that eclipse expeditions are dispatched to the out-of-the-way corners of the Earth. It has been found that the form of the corona depends upon the spottedness of the Sun. At times of spot maximum the corona is nearly circular in general outline, whereas at times of minimum the coronal streamers which extend out from regions of low latitude are extremely long, and the streamers which originate at high latitudes and in the vicinity of the poles of the Sun are very short.

People in general know that the Sun is vital to life on the Earth, but they do not realize that all other sources of energy are negligible. The Sun's light and heat grow the farmers' crops. The solar radiation grows the forests of today. It grew, long ages ago, the luxuriant vegetation which, submerged and compressed, is the coal that today drives the railway trains of the land and the ships of the sea. It is the Sun's power which evaporates the water of the ocean and creates the winds which carry the evaporated water over the mountains where it is deposited as rain and snow. Our hydro-electric plants control the descent of this water from the mountains to the sea, and their water-wheels and dynamos generate electric current. The Sun's energy thus transformed illuminates our cities and drives the trolley cars. We do not depend at all upon the Earth's internal heat. The temperature of the Earth's surface is determined by the heat received from the Sun. To realize this fact, let us recall the frigid conditions perpetually existing at the poles of the

Earth. During several weeks in the middle of the northern summer the north pole receives more solar heat than any other region of the Earth, and thruout the year some of the heat from the tropics and the north temperate zone is constantly transmitted by atmospheric circulation to the north polar region. Similarly, during several weeks in the middle of the southern summer the south pole of the Earth receives more heat than any other region of the Earth, and constantly thruout the year some of the heat of the tropics and of the south temperate zone is conveyed thru the atmosphere to the region of the south pole. Yet how frigid and essentially useless in the vegetable and animal world are the polar regions! The interior heat of the Earth is not able to do anything appreciable for those regions. Now if the Sun's heat were cut off completely from the Earth for one short month, the equatorial regions would be at the end of the month so wintry that the north and south polar regions as they are today are rose gardens in comparison.

To create due respect in our minds for the overwhelming power of the Sun, we may reflect upon the following statement: When the Sun is directly or approximately over any region of the Earth and our atmosphere above that region is in normally clear condition, each square yard of that region receives energy from the Sun's rays at the approximate rate of four-fifths of one horsepower. This is at the rate of 4,000 horsepower per acre. If you own 250 acres of desert in Arizona, or Mexico, or northern Africa, the Sun in the middle of each summer day is pouring down energy upon your little ranch at the rate of one million horsepower. Your neighbor's ranch of the same size is receiving solar energy at the same rate. And so on for the entire surface of the Earth, in proportion as the Sun's rays fall perpendicularly or slantingly upon each area. Yet this is far from the whole story. Nearly the half of the energy which the Sun tries to send to the Earth's surface is intercepted by our atmosphere and turned back into space. With the Sun directly overhead for the various regions of the Earth, only about sixty per cent. of the Sun's energy gets down thru the atmosphere to the land and water surface of the Earth, and the remainder is

refused transmission. Now the Sun, to the best of our knowledge, is sending out energy in all directions at essentially the same rate. The little Earth covers so small an area of the sky, as one would see the sky if he were on the Sun, that the Earth intercepts only one two-billionth part of the Sun's radiation. If we could cover the Sun with a shell of ice forty feet thick, the heat energy radiated from the Sun, at its present rate, would be sufficient to melt that shell of ice in one minute of time. To produce this quantity of energy from the combustion of coal would require that a layer of the best anthracite twelve or fifteen feet deep over the entire solar surface be consumed every hour. Now, if the Sun were composed of anthracite the consumption of the whole mass would not furnish sufficient heat to supply the Sun's output, at the present rate, for as long as 10,000 years. It was Kant in the eighteenth century, and Helmholtz independently a hundred years later, who showed that the contraction of the Sun under the influence of its own gravitational power is the most probable explanation of its source of heat; perhaps not its sole source, but a source which would suffice to maintain the present rate of radiation for many millions of years. The Sun's own gravitational power is struggling constantly to draw every one of its particles to the center of the Sun; it is subjected to its own immense compressive force. Now we know that when we compress air, for the purposes of industry or to fill an automobile tire, a great quantity of heat in the air compressed is liberated and radiated into surrounding space. In the same way the constant and stupendous process of compression which the Sun suffers from its own internal gravitation liberates the heat that is latent within its mass. The immense quantity of energy represented by the actual motion of the Sun's materials inward toward the center is also converted into heat. These are such fruitful sources of heat that the Sun need contract no more than 300 feet per year at the present time to supply the radiation which goes out in all directions and of which a very little reaches us upon the Earth. This is so slow a rate of solar contraction that we could not hope to observe any diminution in the Sun's diameter, even with the most refined measuring

apparatus, until after the passing of some 5,000 years. There can be no doubt that this solar compression will liberate sufficient heat to maintain the present rate of flow for five or ten millions of years, and it can be shown by the application of the same principles that the Sun may well have been radiating heat at an approximately equal rate for five or ten millions of years in the past. It is essentially certain that the radium within the Earth is a powerful factor in developing the Earth's internal heat. We have no evidence as to the existence of radium in the Sun, but it or some of its radio-active relations may be there to assist in giving long life to the Sun and to the planets which draw their sustenance from the Sun.

What can be said as to the existence of life on the other bodies of the solar system? We may dismiss the Sun as too hot to support any form of life with which we are acquainted. Our Moon cannot support life, at least of the terrestrial kinds, because of the total lack of air and water. The probabilities are strong the *Mercury* is lifeless, for the same reason, but this is not a certainty. I think we may dismiss *Jupiter, Saturn, Uranus* and *Neptune* as abodes of life: we do not see how they can have anything in the nature of solid surfaces. *Venus* and *Mars* are the planets most nearly equal in size to the Earth. *Mars* has a very light atmosphere, certainly, but we know nothing as to the extent of *Venus's* atmosphere, except that it has one. If Schiaparelli was right in his conclusion that the planet *Venus* always presents the same face to the Sun, as it probably does, then life on *Venus* would be difficult: one hemisphere would have eternal day with burning temperatures, and the other hemisphere eternal night with extreme cold. *Mars* and the Earth seem to have many resemblances. Seasonal changes occur on *Mars* such as could reasonably be attributed to changes in vegetation; and if there is vegetable life there could well be, and probably is, animal life. However, the vegetable may be easily independent of the animal; the forests and prairies of the Mississippi Valley put on their green clothing in the spring of every year and changed to brown clothing in the fall of every year even better before the coming of "intelligent" man

than after his appearance on the scene. The "canals" of *Mars* may be evidence of intelligent life on that planet; but unless we accompany them with some rather violent assumptions the canals could serve equally well as examples of the lack of intelligence on the planet. How would engineers on the Earth proceed to catch the water from the melting north polar cap of the Earth and use it for irrigation, not only south to the equator, but well down into the southern hemisphere? How would they reverse the process and use the waters from the south polar cap to irrigate not only as far north as the equator but well into the northern hemisphere—it being assumed that there are no oceans to interfere? Would intelligent engineers insist on running their canals absolutely straight for thousands of miles, or would they follow the contours? As the surfaces of the Earth and the Moon are exceedingly unlevel, is it reasonable to assume that *Mars,* half way between the Earth and Moon in size, has a level surface? *Mars* probably has animal life, but in my opinion we have not the proof of it.

I think it is impossible for an intelligent and thoughtful mind to contemplate the orderly solar system, completely isolated from other systems, its great Sun in the center, the tiny planets and the infinitesimal asteroids revolving around the Sun in the same direction and nearly in a common plane, the moons revolving around the planets, all of the planets and asteroids around the Sun from west to east, and nearly all of their moons around their planets from west to east, without saying to ourselves: the members of the solar system have had a common origin; the materials in the Sun, the planets and moons have had a prior existence under other conditions; and the operation of the laws of nature has developed the system to its present state, and will guide its further development to the state which the future has in store for it. Kant's hypothesis would have the development proceed from a great collection of matter in a chaotic state—the same matter which, transformed and redistributed, now composes the system. LaPlace's hypothesis would develop the solar system from a rotating parent nebula. Chamberlin would have the antecedent nebula spiral in structure. This phase of the subject

would demand a full hour for adequate treatment, and we must be content to say that all astronomers believe the solar system to be the product of evolution.

Are there other solar systems than ours? Are there planets revolving around the other stars, as our planets revolve around our Sun? Is there life on planets in other systems? We do not know. We are powerless to answer these questions at present. If we should transport our astronomers and their most powerful instruments to *Alpha Centauri,* the solar system's nearest neighbor, they could not look back and see the planets which attend our Sun. They would see our Sun by naked eye as a first magnitude star, but our greatest planet, *Jupiter,* would be a star of the twenty-first magnitude, and their telescopes at *Alpha Centauri* would have to be at least twenty-five feet in diameter in order to show *Jupiter* as a stellar point of light, just on the limit of vision, even tho the flood of light from our Sun did not interfere with the observation. The fact is that *Jupiter,* as seen from *Alpha Centauri,* would never be more than five seconds of arc from our Sun, and the glare of sunlight in the Centauran telescope would hopelessly drown the image of *Jupiter,* even tho the diameter of the telescope were much greater than twenty-five feet. The latter difficulty would resemble that of trying to see a glow worm that is two feet to the right or left of a powerful searchlight located sixteen miles from the observer.

Altho we have not been able to secure direct and positive evidence in favor of other planetary systems, and altho we see no promise of such evidence in the future, it would be unreasonable to believe that such planetary systems do not exist. It would be contrary to the simple probabilities if our Sun, one of several hundred millions of suns, were the only Sun attended by planets, and our Earth were the only planet that is the abode of life. We are not able to prove that we have neighbors scattered thruout the great stellar universe, but we are justified, I think, in believing that they are there.